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HUMAN MUSCULOSKELETAL TOLERANCE LIMITS TO EJECTION AND RELATED --ETC(U)
JUL 77 A H BURSTEIN AF-AFOSR-2820-75

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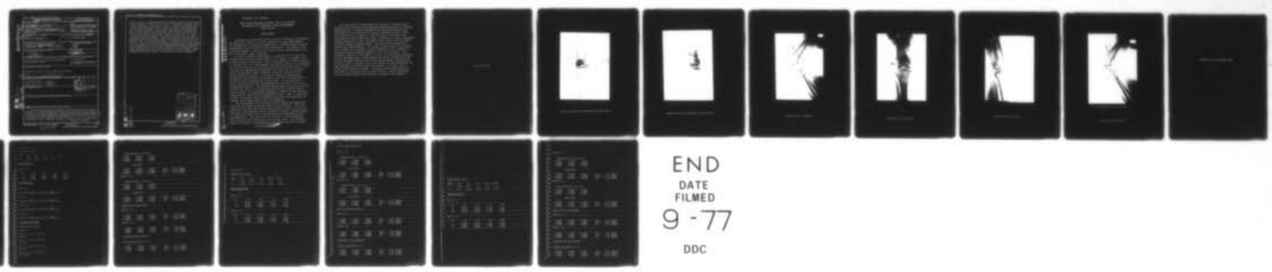

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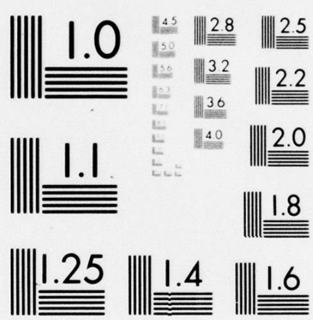

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A scheme was devised for determining the mechanical stiffness of joints subjected to large displacements. The knee joint was chosen as a developmental anatomical structure. A system for taking two simultaneous orthogonal x-rays was constructed. Marking grids were superimposed upon the film at the time of radiographic exposure, enabling the precise location of the x-ray source to be calculated; thus all recognizable landmarks or markers on the tibia and femur

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could be located in three-dimensional space. With successive bi-plane x-rays taken at different intensities and directions of loading, a stiffness matrix could be formulated. A second phase utilized a simple one-dimensional load cell which measured applied loads. Loads were recorded on an oscilloscope and strain gage amplifiers. Orientation of the force in three-dimensional space could be visualized on the bi-plane films, enabling a precise calculation of the geometry of the loading system to be made. The first series was conducted on fresh cadaver knees. Loads were applied so as to produce a varus and valgus displacement. Simultaneous bi-plane films were taken. Radiographic markers consisting of small load spheres were inserted into the tibia and femur through cutaneous wounds. The repeatable location of such markers is vital to the measuring technique. Comparison must be made between the results obtained with the precise red opaque markers and the less precise manual determinations of marker points. Volunteers were selected for the same procedures except that no marker system would be utilized. Successive paired radiographs were taken at various positions of knee flexion. Sample radiographs and reduced computer data forms were obtained and analyzed.

AFOSR-TR- 77-0884

HUMAN MUSCULOSKELETAL TOLERANCE LIMITS TO EJECTION AND RELATED HIGH MECHANICAL STRESS ENVIRONMENTS

AFOSR-75-2820

FINAL REPORT

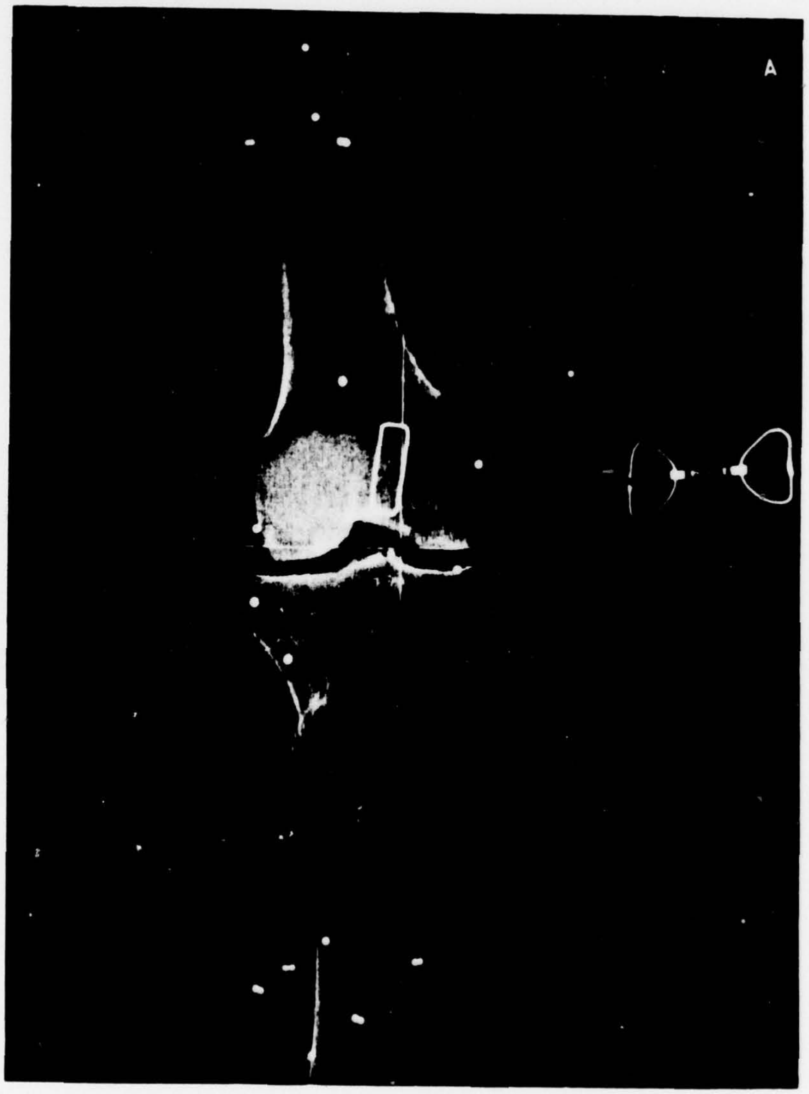
The purpose of the project was to initiate a scheme for determining the mechanical stiffness of joints subjected to large displacements. The methodology to be developed would allow a stiffness matrix relating displacements and rotations to forces and moments. Two phases of the study were planned. The first phase would utilize cadaver material and the second phase, human volunteers.

In order to measure displacements, a process had to be developed whereby accurate position measurements of the femur, for example, must be made relative to the tibia. Since it was decided to center attention on the knee joint as a developmental anatomical structure, all subsequent work for the duration of the project was performed on knee joints. The technique for displacement measurement was based upon an existing bi-plance radiographic viewing technique previously developed at Case Western Reserve University. A system for taking two simultaneous orthogonal x-rays had been constructed so that the films were held at planes that were perpendicular to each other. At the same time, a system of marking grids was superimposed upon the film at the time of radiographic exposure. This marking system enabled the precise location of the x-ray source to be calculated and with that precise relative location known, all recognizable landmarks or markers on the tibia and femur could be located in three-dimensional space. Thus, if successive bi-plane x-rays were taken at different intensities and directions of loading, the stiffness matrix could be formulated.

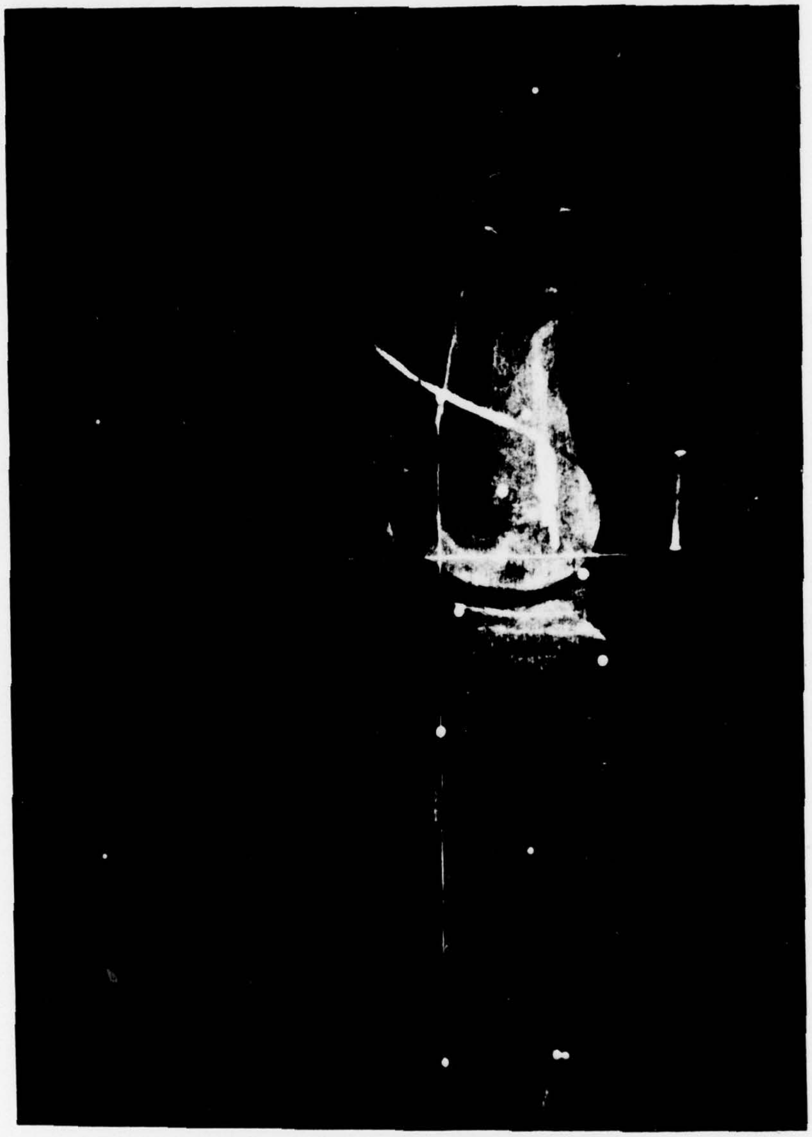
The second phase of the system utilized a simple one-dimensional load cell with which the applied loads could be measured. The final design for the operational system would probably require at least one additional load measuring device, preferably a device to measure moment. All loads were recorded on an oscilloscope using appropriate strain gage amplifiers. The orientation of the force in three-dimensional space could also be visualized on the bi-plane films. This enabled a precise calculation of the geometry of the loading system to be made.

The first series of experiments was conducted on cadaver knees obtained from patients who had undergone amputation because of vascular insufficiencies. A special holding device was manufactured and the specimens were held within the bi-plance radiographic frame. Loads were applied so as to produce a varus and valgus displacement and simultaneous bi-plane films were taken. Subsequent to that, radiographic markers consisting of small load spheres were inserted into the tibia and femur through cutaneous wounds. The process was repeated with similar data being obtained. The purpose of this duality of procedure was to enable the researchers to gain confidence in their ability to repeatedly locate anatomical markers on the tibia and femur. The repeatable location of such markers is vital to the measuring technique and the comparison must be made between the results obtained with the precise red opaque markers and the less precise manual determinations of marker points. Volunteers were then selected to have essentially the same procedures carried out with the exception, of course, that no marker system would be utilized. Successive paired radiographs were then taken at various positions of knee flexion. Sample radiographs and the reduced computer data forms are included in the Appendix.

A P P E N D I X

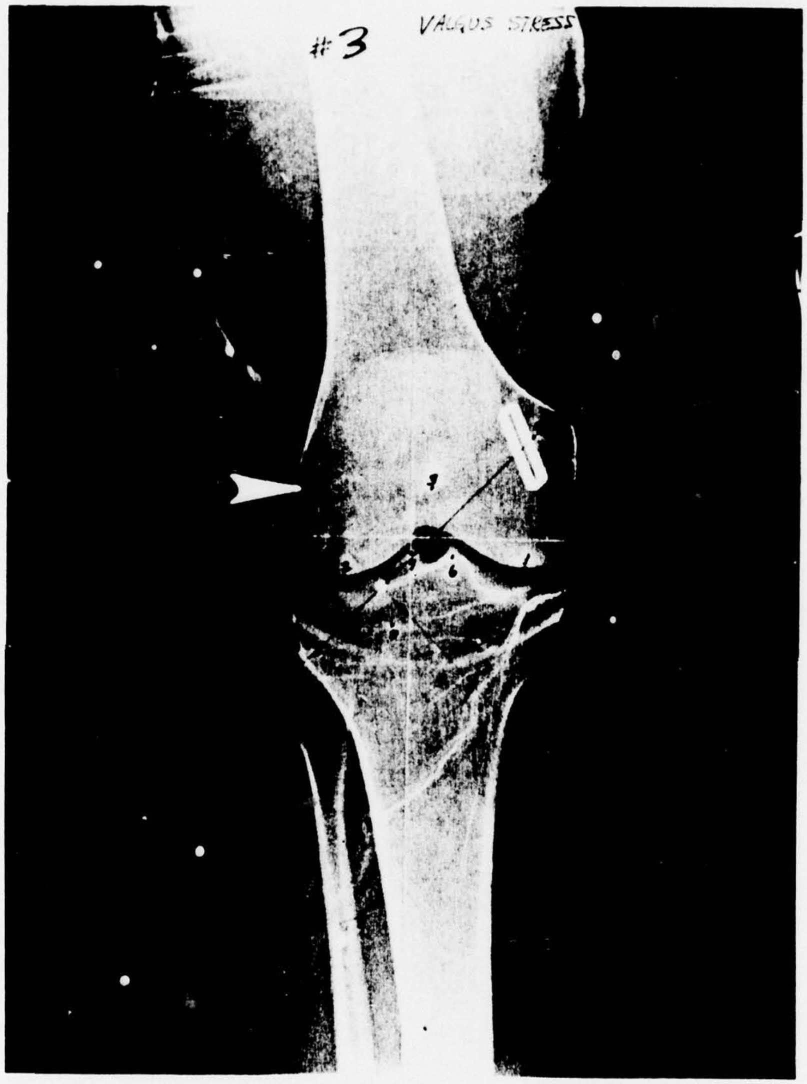


Cadaver Knee Without Calibrated Loading Device

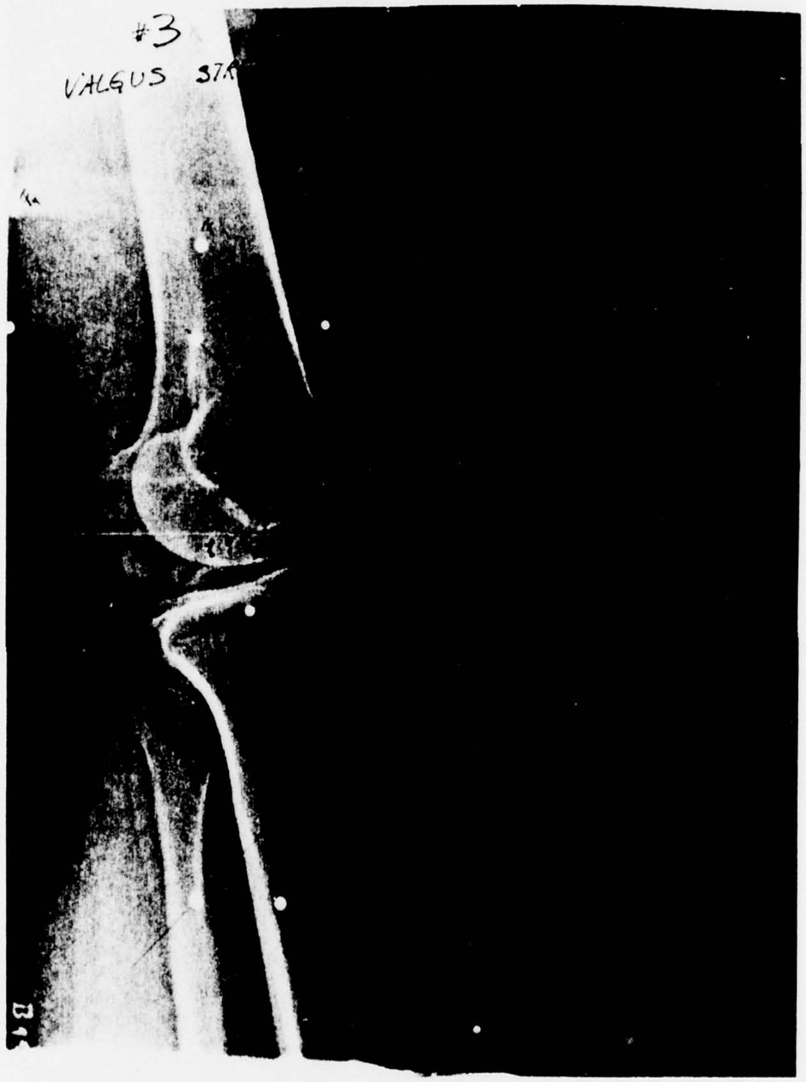


Cadaver Knee With Calibrated Loading Device

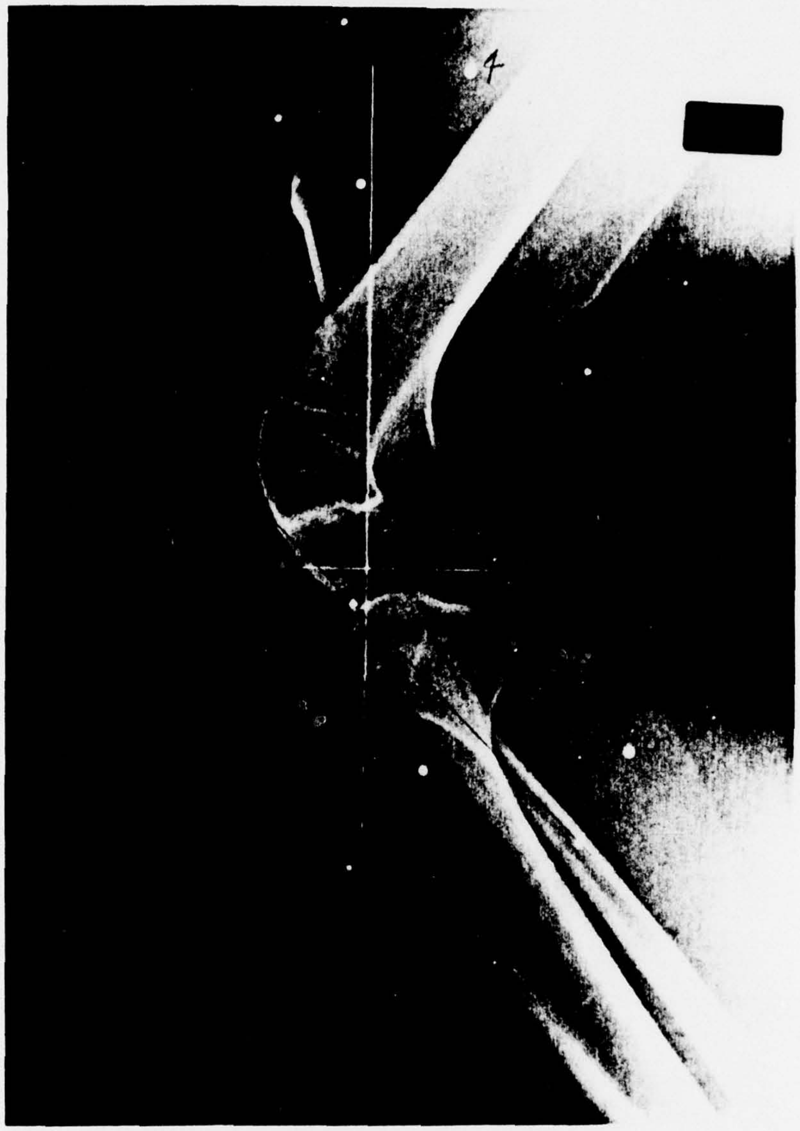
Volunteer Knee - Unloaded



Volunteer Knee in Stress



Volunteer Knee in Stress



Volunteer Knee in Stress

KINEMATIC DATA IN REDUCED FORM

FILM SET NO. = 1

AVERAGE CAMERA POSITIONS

CAMERA	X POS	Y POS	Z POS	AVG ERR	MAX ERR
A	44.050	122.413	-1.869	0.015	[illegible]
B	138.628	29.564	-1.646	0.056	0.110

OBJECT POINTS IN 3-D
****

BODY NO. = PLV

PT NO	X POS	Y POS	Z POS	ERROR
1	39.088	32.480	13.995	0.1628
2	38.310	26.307	10.410	0.0935
3*	35.857	37.609	11.671	0.1573
4*	40.926	33.553	11.126	0.1338

OBJECT POINTS IN 3-D
****

POINT NO. = 1

A (3.578 -9.566), B (-4.116 -9.888)
PO(X,Y,Z) (34.929 26.138 -7.867), ERROR =0.0556

POINT NO. = 2

A (1.246 -17.101), B (3.900 -16.972)
PO(X,Y,Z) (37.204 32.090 -12.983), ERROR =0.1245

POINT NO. = 3

A (-0.024 -12.075), B (6.184 -11.912)
PO(X,Y,Z) (38.253 33.710 -9.172), ERROR =0.0926

POINT NO. = 4

A (10.311 -6.728), B (10.563 -6.133)
PO(X,Y,Z) (31.318 37.381 -5.182), ERROR =0.0625

EULERIAN SPATIAL DESCRIPTION
****

NORMALIZED SPATIAL DESCRIPTION

POINT NO. = 1

PN(X,Y,Z) (-20.788 -17.553 -34.999)

POINT NO. = 2

PN(X,Y,Z) (-19.619 -18.640 -43.013)

POINT NO. = 3

PN(X,Y,Z) (-20.850 -22.526 -41.733)

POINT NO. = 4

PN(X,Y,Z) (-14.142 -27.108 -38.343)

FILM SET NO = 2

AVERAGE CAMERA POSITIONS

CAMERA	X POS	Y POS	Z POS	AVG ERR	MAX ERR
A	43.472	122.994	1.544	0.037	0.091
B	137.882	30.331	-2.160	0.062	0.108

OBJECT POINTS IN 3-D
****

BODY NO. = PLV

PT NO	X POS	Y POS	Z POS	ERROR
1	38.798	32.041	15.483	0.1729
2	37.929	26.005	11.671	0.1091
3*	35.656	37.300	13.370	0.1775
4*	40.664	33.185	12.659	0.1475

OBJECT POINTS IN 3-D
****

POINT NO. = 1

```
A (  2.311  -7.584  ),   B (  -5.642  -6.893  )
PO(X,Y,Z) (  35.724  25.237  -5.689  ),   ERROR =0.0222
```

POINT NO. = 2

```
A (  0.466 -15.834  ),   B (  1.856 -14.716  )
PO(X,Y,Z) (  37.540  30.796 -11.390  ),   ERROR =0.0926
```

POINT NO. = 3

```
A ( -0.482 -11.247  ),   B (  4.784  -9.823  )
PO(X,Y,Z) (  38.374  32.899  -7.758  ),   ERROR =0.0676
```

POINT NO. = 4

```
A (  10.232  -6.765  ),   B (  8.878  -4.839  )
PO(X,Y,Z) (  31.011  36.258  -4.276  ),   ERROR =0.0396
```

EULERIAN SPATIAL DESCRIPTION
****

NORMALIZED SPATIAL DESCRIPTION

POINT NO. = 1

PN(X,Y,Z) (-1.895   5.469 30.842)

POINT NO. = 2

PN(X,Y,Z) (2.496   3.143 37.323)

POINT NO. = 3

PN(X,Y,Z) (2.250   7.382 37.854)

POINT NO = 4

PN(X,Y,Z) (8.309 11.543 32.996)

FILM SET NO. = 3

AVERAGE CAMERA POSITIONS

CAMERA	X POS	Y POS	Z POS	AVG ERR	MAX ERR
A	43.504	123.088	1.338	0.0[illegible]	0.058
B	137.969	30.353	-2.395	0.035	0.101

OBJECT POINTS IN 3-D
****

BODY NO. = PLV

PT NO	X POS	Y POS	Z POS	ERROR
1	38.644	32.618	15.610	0.1769
2	38.190	26.312	12.124	0.1098
3*	35.214	37.493	13.169	0.1782
4*	40.492	33.645	12.775	0.1514

OBJECT POINTS IN 3-D
****

POINT NO. = 1

```
A  (   1.123   -6.271   ),   B  (  -7.369   -5.612   )
PO(X,Y,Z)  (  36.588  24.015  -4.773   ),   ERROR =0.0137
```

POINT NO. = 2

```
A  (  -0.263 -15.003   ),   B  (  -0.608 -14.259   )
PO(X,Y,Z)  (  37.991  29.011 -11.071   ),   ERROR =0.0794
```

POINT NO. = 3

```
A  (  -0.937 -10.912   ),   B  (   2.904   -9.681   )
PO(X,Y,Z)  (  38.643  31.545  -7.706   ),   ERROR =0.0659
```

POINT NO. = 4

```
A  (   9.967   -7.063   ),   B  (   6.829   -5.262   )
PO(X,Y,Z)  (  30.980  34.676  -4.657   ),   ERROR =0.0389
```

EULERIAN SPATIAL DESCRIPTION
****

NORMALIZED SPATIAL DESCRIPTION

POINT NO. = 1

```
PN(X,Y,Z)  (  -2.649   0.825  36.594   )
```

POINT NO. = 2

```
PN(X,Y,Z)  (   2.987   3.958  41.596   )
```

POINT NO. = 3

```
PN(X,Y,Z)  (  -0.636   5.607  43.121   )
```

POINT NO. = 4

```
PN(X,Y,Z)  (  -2.999  12.720  38.468   )
```

END OF PROGRAM

TRANSLATED POINTS, (XVT, YVT, ZVT)

0.09757	2.01082	-1.28785
0.09760	2.01083	5.88410
-2.38895	-3.23017	-4.18351
2.58408	-0.52902	-0.97852

EULER MATRIX

0.97062	0.01654	-0.24005	PHI =	82.763	DEGREES
0.21464	-0.51038	0.83273	THETA =	-60.049	DEGREES
-0.10874	-0.85979	-0.49894	PSI =	73.894	DEGREES
38.43091	32.39351	11.68000	DT =	51.601	CMETERS

BODY NO. = C2
....

TRANSLATED POINTS, (XVT, YVT, ZVT)

-0.18961	3.67938	4.90877
-0.18962	3.67938	-3.25288
-2.62004	0.29200	-2.34145
2.24083	-6.81546	-0.59106

EULER MATRIX

-0.91996	0.01528	-0.39172	PHI =	69.046	DEGREES
0.27578	-0.68494	-0.67439	THETA =	51.234	DEGREES
-0.27861	-0.72844	0.62590	PSI =	-59.829	DEGREES
35.12001	32.23981	-8.52524	DT =	48.430	CMETERS

NORMALIZED SPATIAL DESCRIPTION
....

BODY NO. = C1
....

-0.79865	0.41823	-0.43271	PHI =	72.473	DEGREES
-0.53145	-0.15281	0.83319	THETA =	69.836	DEGREES
0.28235	0.89539	0.34431	PSI =	62.533	DEGREES
-10.95826	-12.81844	11.61209	DT =	20.475	CMETERS

BODY NO. = C2
....

1.00000	-0.00000	0.00000	PHI =	-0.000	DEGREES
-0.00000	1.00000	0.00000	THETA =	0.000	DEGREES
0.00000	0.00000	1.00000	PSI =	0.000	DEGREES
0.00000	0.00000	0.00000	DT =	0.000	CMETERS

INTERSEGMENT SPATIAL DESCRIPTION
....

INTERSPACE RELATIONSHIP C1 , C2
....

-0.79865	0.41823	-0.43271	PHI =	72.473	DEGREES
-0.53145	-0.15281	0.83319	THETA =	69.836	DEGREES
0.28235	0.89539	0.34431	PSI =	62.533	DEGREES
0.16170	0.00750	0.98681	SEP =	20.475	CMETERS

FILM SET NO. = 1

AVERAGE CAMERA POSITIONS

CAMERA	X POS	Y POS	Z POS	AVG ERR	MAX ERR
A	43.472	122.415	1.544	0.037	0.091
B	137.540	30.331	-2.160	0.062	0.108

OBJECT POINTS IN 3-D
****

BODY NO. = C1

PT NO	X POS	Y POS	Z POS	ERROR
1	38.806	32.038	15.463	0.1706
2	37.936	26.009	11.657	0.1093
3*	35.672	37.292	13.351	0.1735
4*	40.669	33.182	12.641	0.1459

BODY NO. = C2

PT NO	X POS	Y POS	Z POS	ERROR
1	35.734	25.242	-5.683	0.0193
2	37.550	30.794	-11.375	0.0871
3	38.383	32.896	-7.747	0.0626
4	31.035	36.252	-4.269	0.0350

ABSOLUTE SPATIAL DESCRIPTION
....

BODY NO. = C1
....

TRANSLATED POINTS, (XVT, YVT, ZVT)

0. 09688	2. 00350	-1. 28698
0. 09688	2. 00350	5. 89532
-2. 39401	-3. 21192	-4. 19892
2. 58777	-0. 53392	-0. 97723

EULER MATRIX

0. 97135	0. 00977	-0. 23744	PHI =	81. 765	DEGREES
0. 20449	-0. 54341	0. 81418	THETA =	-57. 985	DEGREES
-0. 12107	-0. 83741	-0. 52984	PSI =	73. 716	DEGREES
38. 14601	32. 04581	13. 17250	DT =	51. 532	CMETERS

BODY NO. = C2
....

TRANSLATED POINTS, (XVT, YVT, ZVT)

-0. 19014	3. 66935	4. 89725
-0. 19014	3. 66935	-3. 25920
-2. 64126	0. 28909	-2. 34349
2. 26101	-6. 79229	-0. 56457

EULER MATRIX

-0. 90896	-0. 11380	-0. 40104	PHI =	71. 860	DEGREES
0. 35242	-0. 72366	-0. 59339	THETA =	45. 726	DEGREES
-0. 22269	-0. 68071	0. 69789	PSI =	-55. 928	DEGREES
35. 35820	31. 20921	-6. 99912	DT =	47. 678	CMETERS

NORMALIZED SPATIAL DESCRIPTION
....

BODY NO. = C1
....

-0. 78881	0. 47614	-0. 38867	PHI =	64. 546	DEGREES
-0. 45055	-0. 01782	0. 89257	THETA =	76. 759	DEGREES
0. 41806	0. 87919	0. 22859	PSI =	66. 446	DEGREES
-10. 71893	-11. 59267	12. 88718	DT =	20. 381	CMETERS

BODY NO. = C2
....

1. 00000	-0. 00000	-0. 00000	PHI =	-0. 000	DEGREES
-0. 00000	1. 00000	0. 00000	THETA =	0. 000	DEGREES
-0. 00000	0. 00000	1. 00000	PSI =	0. 000	DEGREES
0. 00000	0. 00000	0. 00000	DT =	0. 000	CMETERS

INTERSEGMENT SPATIAL DESCRIPTION
....

INTERSPACE RELATIONSHIP C1 , C2
....

-0. 78881	0. 47614	-0. 38867	PHI =	64. 546	DEGREES
-0. 45055	-0. 01782	0. 89257	THETA =	76. 759	DEGREES
0. 41806	0. 87919	0. 22859	PSI =	66. 446	DEGREES
0. 13679	0. 04105	0. 98975	SEP =	20. 381	CMETERS

AVERAGE CAMERA POSITIONS

CAMERA	X POS	Y POS	Z POS	AVG ERR	MAX ERR
A	43.505	122.509	1.339	0.036	0.058
B	137.626	30.353	-2.395	0.035	0.101

OBJECT POINTS IN 3-D
****

BODY NO. = C1

PT NO	X POS	Y POS	Z POS	ERROR
1	38.812	32.046	15.405	0.1767
2	37.941	26.016	11.605	0.1194
3*	35.680	37.299	13.291	0.1732
4*	40.676	33.189	12.581	0.1526

BODY NO. = C2

PT NO	X POS	Y POS	Z POS	ERROR
1	35.739	25.246	-5.735	0.0101
2	37.558	30.799	-11.435	0.0814
3	38.391	32.902	-7.809	0.0579
4	31.041	36.257	-4.327	0.0394

BODY NO. = C1

TRANSLATED POINTS, (XVT, YVT, ZVT)

0.09671	2.00386	-1.28602
0.09667	2.00386	5.89493
-2.39496	-3.21009	-4.19867
2.58840	-0.53695	-0.97768

EULER MATRIX

0.97136	0.00930	-0.23742	PHI =	81.751	DEGREES
0.20429	-0.54290	0.81457	THETA =	-58.025	DEGREES
-0.12132	-0.83975	-0.52925	PSI =	73.725	DEGREES
38.15260	32.05281	13.11550	DT =	51.527	CMETERS

BODY NO. = C2

TRANSLATED POINTS, (XVT, YVT, ZVT)

-0.19020	3.66937	4.89954
-0.19020	3.66937	-3.26313
-2.64111	0.29044	-2.34720
2.26074	-6.79323	-0.56200

EULER MATRIX

-0.90897	-0.11395	-0.40098	PHI =	71.845	DEGREES
0.35235	-0.72402	-0.59300	THETA =	45.696	DEGREES
-0.22275	-0.68031	0.69826	PSI =	-55.914	DEGREES
35.36481	31.21411	-7.05666	DT =	47.695	CMETERS

NORMALIZED SPATIAL DESCRIPTION

BODY NO. = C1

-0.78880	0.47632	-0.38847	PHI =	64.537	DEGREES
-0.45046	-0.01799	0.89261	THETA =	76.750	DEGREES
0.41818	0.87909	0.22875	PSI =	66.458	DEGREES
-10.71821	-11.58700	12.89390	DT =	20.381	CMETERS

BODY NO. = C2

1.00000	0.00000	-0.00000	PHI =	0.000	DEGREES
0.00000	1.00000	0.00000	THETA =	0.000	DEGREES
-0.00000	0.00000	1.00000	PSI =	0.000	DEGREES
0.00000	0.00000	0.00000	DT =	0.000	CMETERS

INTERSEGMENT SPATIAL DESCRIPTION

INTERSPACE RELATIONSHIP C1 , C2

-0.78880	0.47632	-0.38847	PHI =	64.537	DEGREES
-0.45046	-0.01799	0.89261	THETA =	76.750	DEGREES
0.41818	0.87909	0.22875	PSI =	66.458	DEGREES
0.13678	0.04115	0.98975	SEP =	20.381	CMETERS